Configuring Geographically Distributed Videotex Databases: Model and Solution Procedure

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Videotex refers to computer-based interactive systems that are capable of electronically delivering screen text, numbers and graphics via telephone or two-way cable for display on television sets or video monitors. This technology allows computer-naive users to easily access general interest or highly specialized information stored in on-line databases in the amount and sequence (s)he desires. Over the past decade, there has been considerable interest in videotex systems, and a number of them have already been implemented in different countries. With the proposed implementation of Integrated Services Digital Networks, the interest in videotex systems is expected to grow even further.

This paper provides a brief overview of commercial videotex systems in various countries, and discusses possible organizational usage of these systems. In addition, we formulate a 0/1 integer programming model for allocating videotex files in a geographically distributed videotex system. A Lagrangian relaxation based solution procedure is developed for solving the videotex file allocation problem. Results of extensive numerical experiments performed using the proposed heuristic solution procedure are reported.

Videotex refers to computer-based interactive systems that are capable of electronically delivering screen text, numbers and graphics via telephone or two-way cable for display on television sets or video monitors (Augmente, 1987). Using retrofitted personal computers or special videotex terminals, subscribers(users) can access general interest or highly specialized information stored in on-line, videotex databases. These databases consist of a network of 'pages' or 'frames' that the user can navigate using simple commands, such as menu selection, keyword searches and form filling (Gescei, 1985). Usually, the subscriber is charged for connect time, and the number of pages referenced. Videotex provides the user with a simple interface to access large amounts of data quickly, in the amount and sequence (s)he desires.

First generation videotex systems (VS) were essentially low cost public information retrieval services. However, over the past decade, the emphasis has shifted to using videotex as a communication medium rather than a simple information retrieval system. Currently, VS are being used for accessing multiple independent databases, messaging, and electronic mail. These systems have also been used extensively for conducting interactive, transactional services such as home banking and tele-shopping.

Over the past few decades, tele-communication networks have been designed and implemented to support a wide variety of services, including the integration of a customer's voice, data and video communication requirements. Rapid advances in VLSI technology, coupled with declining costs of fiber-based transmission systems, have resulted in high speed, broadband digital networks capable of transporting hundreds of megabits per second. The most attractive of all recent trends is the expected deployment of Integrated Services Digital Network (ISDN). Growing from the need to eliminate different access methods and equipments for each kind of service (e.g. voice, data, video) desired by a customer, the primary objectives of ISDN are (i) to provide integrated access via a single set of wires, (ii) to establish an internationally standardized protocol, and (iii) provide digital end-to-end connectivity. Due to the proposed

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implementation of ISDN and the consequent availability of digital, high speed communication links, interest in VS will continue to increase in the immediate future.

In addition to information retrieval and transactional services on centralized databases, most currently implemented videotex systems provide facilities that allow transparent gateways to other databases and services. The user-friendly, interactive nature of VS, coupled with the ability to access multiple databases easily from a single desktop computer system, has important implications for the organizational use of these systems. Videotex has the potential of presenting easily updatable and timely information to computer-naive users. Thus, from an organizational standpoint, VS provides the advantages of a wider information base, both internal and external. Currently, organizations must spend significant amount of time and effort to train end users on how to use the information system. Due to the inherent simplicity of videotex systems, this training time (and associated costs) can be reduced considerably.

Components of a Videotex System

In general, subscribers access on-line videotex information via special user terminals. These terminals are connected to a communications medium, usually telephone lines or two way cable. A keypad is attached for selecting options that appear on the screen. Currently, however, the trend is towards the use of personal computers with 'videotex cards' instead of specialized user terminals. The information in the databases are maintained and updated by a set of suppliers known as Information Providers (IP).

Users and information providers are connected to the Information Services System (ISS). The ISS can be partitioned into:

- Information Retrieval System (IRS),
- Information Update Server (IUS), and
- Gateway Service Provider (GSP).

Subscribers(users) interact directly with the IRS. Based on the user's request, the IRS retrieves the appropriate data from the videotex database. When the required data is not available at the local IRS, the request can be transferred through the GSP to a geographically distant information retrieval system. Usage accounting is handled by the IRS.

Data from information providers are received by the IUS. If the data is already in videotex format, the IUS forwards the data to the associated IRS. Otherwise, before distributing the data, the IUS reformats the data to an appropriate form. Electronic mail, file transfer, and access to remote locations (databases) are handled by the GSP. The inter-connections between various components of a videotex system are shown in Figure 1.

Objectives of this Paper

The objectives of this paper are two fold. First, it is our intention to provide an outline of existing, commercial videotex systems and discuss the organizational uses of this technology. Available literature on videotex systems are dominated by discussions on protocol standards, hardware design, and various marketing, psychological, and social aspects of these systems. There is, surprisingly, a scarcity of literature concerning analytic foundations for designing these systems. Accordingly, our second goal is to provide an analytic tool for allocating videotex files in a geographically distributed videotex system, henceforth referred to as a videotex network (VN). There are marked similarities between a VN and distributed databases, and hence models developed for the latter can be utilized for designing VN. However, due to some special properties of videotex, considerably simpler solution procedures can be developed. We propose a Lagrangian relaxation based solution procedure for solving the videotex file allocation problem.

The remainder of this paper is organized as follows: Section 2 provides an overview of commercial videotex implementations in different countries, and discusses possible organizational uses of these systems. The subsequent section details a 0/1 integer programming model for allocating videotex files. Section 4 presents the proposed solution procedure and results of computational experiments. Section 5 points out the limitations of this research, provides directions for future work, and concludes this paper.

Commercial Videotex Systems

Development of videotex in European countries and the U.S. have followed different patterns. In Europe, nationwide videotex networks, subsidized heavily by the national government, have been established. Consequently, due to governmental regulations, there has been a high degree of standardization in conventions and protocols, thus aiding further development of VS. Additionally, governmental involvement and subsidies have helped defray some of the initial setup costs, thereby reducing the financial commitment required from the eventual users. This has resulted in large subscriber bases. In United States, on the other hand, videotex has been in the hands of the private industry, each attempting to provide a novel (and often incompatible) service. To a large extent, this has contributed to lack of standards and small subscriber bases for each videotex provider, thus hampering the development of these systems (Gescei, 1985). To start with, this section provides an overview of commercial videotex implementations in U.S.A. and other countries.

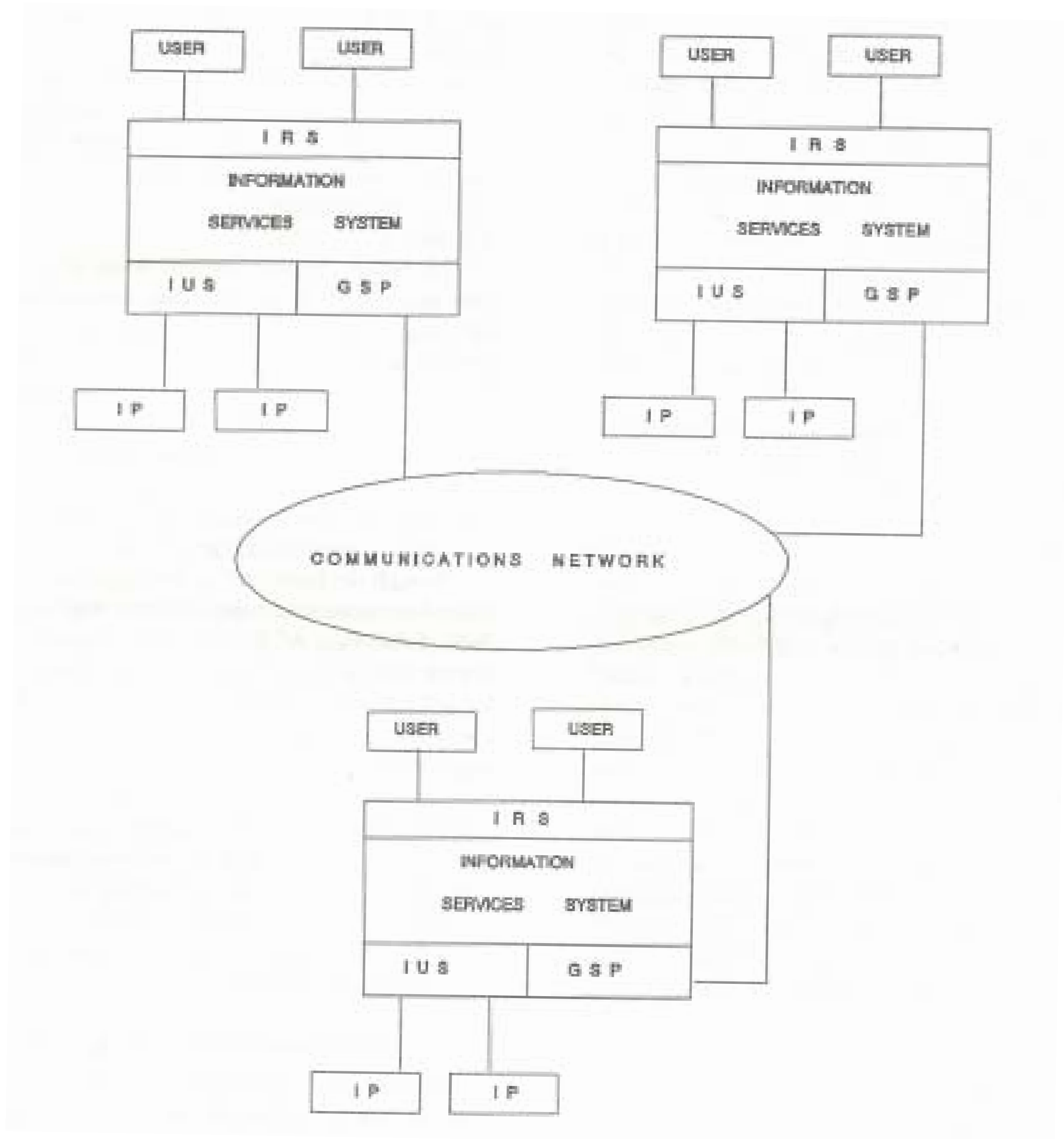

Figure 1: Components of a Videotex System

Videotex Implementations Outside U.S.A.

Videotex was developed at the British Telecommunications Research Laboratories in 1971. The primary motivation for developing VS was to increase telephone use and provide assistance for the hearing impaired through closed captioning of broadcasts (Augmente, 1987). The first commercial, public videotex service, known as Prestel, opened in London in 1979. Besides simple database retrieval, Prestel featured an inter-subscriber message service, and transactional applications for ticket reservations. By the mid 1980s, Prestel had over 300,000 pages in the database, provided (and updated) by around 1,000 information providers/sources. The subscriber base was approximately 65,000, 98% of which could access Prestel via a local telephone call. Forty five percent of Prestel subscribers were businesses. In Prestel, users pay the communication costs of accessing the VS, and a fixed subscription fee every quarter. In addition, subscribers must pay a variable fee based on the number of pages accessed.

One of the most successful implementations of videotex has been in France. The nation-wide videotex service was created in conjunction with the national telephone system. Services provided include an electronic telephone book containing the listing of all telephone subscribers in France. Telephone authorities distribute, free of charge, a small (9-inch black & white or 11-inch color) portable videotex terminal, an alphanumeric keyboard, and a 1200 baud modem to each subscriber. More sophisticated versions of these terminals, with limited processing capability, memory, and the ability to receive electronic mail, are also available. By 1986, the French VS contained over 2,000 information providers, including approximately 150 media services, and an equal number specializing in financial services, banking, retailing, and merchandizing (Augmente, 1985). User access to most databases and services are routed through a centralized billing facility called the Kiosk. For each service used, the user is billed directly by the telephone company, which in turn, shares the revenue with the information provider. Users have the flexibility of subscribing exclusively to individual videotex services, and are billed directly by the associated information provider.

The West German Bildschirmtext VS has a database comparable in size to that of Prestel (Gescei, 1985). Furthermore, through gateways and special interfaces, users can access additional services on independent computer systems owned by various banks, airlines and department stores. Southam Inc. and Torstar Corp., two of Canada's leading communication and publishing firms, have formed Infomart that operates various services: Grassroots, for farmers; Teleguide, a visitor's guide to Toronto; Cantel, a government information service; Private File Service, a service for corporate and private sector clients with storage search and data management (Augmente, 1987). Since 1982, Infomart has successfully operated Teleguide, providing detailed city maps, and extensive information regarding weather, cultural events, hotels, and restaurants.

Videotex Implementations in U.S.A.

Though by 1986 there were over 100 videotex systems in the United States, initial experiences have been disappointing. Viewtron, owned by Knight-Ridder Newspaper Inc., began commercial operations in South Florida in 1983. Consisting of approximately 300,000 frames of information, Viewtron had color and quality graphics. It introduced AT&T's Sceptre videotex terminals (sold for $900) as the only way to access the system. Largely due to consumer resistance to these limited usage, high priced terminals (later discounted to $600), and partially due to gross over-estimation of the market for on-line services, Viewtron shut down in March 1986.

In 1984 Time Mirror Inc. launched Gateway videotex services in Southern California. Subscribers had to rent or buy the AT&T Sceptre terminals to access this service. With over 40 information providers, the Gateway database included top news stories and information on health, education, entertainment, dining and travel. In addition, it featured interactive games, home shopping, electronic mail and home banking. Unlike Viewtron, Gateway banked on attracting huge advertising revenues in order to keep user fees at a reasonable level. However, it soon realized that a major portion of its limited subscriber base were computer hobbyists, not particularly interested in commercials for home shopping and banking. With advertisement revenues decreasing and marketing costs spiralling up, Gateway folded in 1986.

The major lesson learned from the Gateway and Viewtron experiences was that home consumers were unwilling to invest a large amount of money for special videotex terminals, that had limited functionality and power. In later stages, both Gateway and Viewtron had experimented with 'videotex access kits' provided, for a nominal fee, to subscribers with personal computers. Though these experiments were successful, they were too late to resurrect these videotex operations. Consequently, recent videotex services have emphasized access via personal computers.

Through the latter half of the eighties, three major alliances have revitalized the videotex market in the United State of America. AT&T, Time Inc., Bank of America and Chemical Bank have created Covidea, aimed at home banking and small businesses. IBM, CBS, and Sears have joined forces to start Trintex, a national VS specializing in local and national news, financial data, messaging, banking, shopping, and entertainment. Citibank, NYNEX and RCA have also formed an alliance to start a videotex system. By the early 1990s, the number of videotex users in U.S.A is expected to reach almost a million (Augmente, 1987). This projection includes subscribers of text only, on-line, 'videotex like' services such as Compuserve, The Source, and Dow Jones New/Retrieval.

Organizational Uses of Videotex

Videotex was originally envisaged as an information retrieval medium for the home consumer market. As a result, videotex systems were designed to provide widespread access through simplicity, user-friendliness and low cost. These features have contributed to increased adoption of VS for home banking and home shopping. Though this technology will have to eventually prove its credibility in the residential market, the economic benefits in this market are hard to perceive and quantify (James, 1983). James (1983) posits that the business market, on the other hand, has more clearly defined information needs and is prepared to invest in order to satisfy those need. The major organizational application of videotex is as an office automation tool. The following section discusses this in greater detail.

Videotex as an Office Automation Tool

The primary objective of office automation (OA) is to increase productivity by making the power of computers available to office workers. However, even today, a large percentage of this group remains computer naive. As a result, widespread acceptance of an OA tool hinges on the simplicity of user interfaces and low user learning time --- features that are fundamental to any videotex system.

Most organization spend enormous amount of money in typesetting, printing, warehousing and distributing volatile information (Leeson, 1983). Though an individual office worker may require this information infrequently, organization wide collective demand of such information can be significant. Since videotex systems can be updated easily, as an electronic publishing medium these systems alleviate the problem of obsolete and inaccurate information associated with printed documents. Furthermore, since this information retrieval medium is user-driven, (s)he can selectively control the amount of information to be displayed, and thus easily avoid being submerged by data. Private videotex systems have been used for storing organizational structures, employee lists/responsibilities, product information and diaries of management and sales personnel (Hunt & Gilbert, 1983).

In addition to electronic publishing/information retrieval, videotex offers other useful capabilities. First, VS handle electronic mail, bulletin boards and electronic messaging, tools considered essential for enhancing communication in the work place. Second, a videotex system can be implemented on a front-end processor that is connected to the central mainframe or a bank of mini-computers. In addition to the applications discussed thus far, this configuration, provides a 'friendly' interface allowing inexperienced users a gateway to existing mainframe applications and external networks (Roberts, 1983).

Most organizations need to communicate with independent external users (EU), such as dealers, retailers, agents and middlemen. Though EU can electronically access an organization's order entry system (to either place or inspect order status) via the public switched telephone network, two major problems exist with this mode of access. First, it is unlikely that an organization will be able to impose the mechanics of its own system on independent external entities. Second, it is unreasonable to expect an external user interacting with multiple organizations, to learn the intricacies of different information systems. In such situations, Videotex, providing easy-to-use, low cost interfaces, promises to be an attractive alternative as the communications medium (Roberts, 1983). External users can be buffered from the specifics of a particular information system by implementing videotex on the front-end processor.

Potential organizational uses of videotex systems are readily apparent. However, given the widespread proliferation of micro-computers in the work place today, it is unlikely that organizations will undertake additional investment in special videotex terminals, unless they are widely available and inexpensive. As a result, it is believed that videotex implementations in the business sector must rely heavily on the use of special boards/cards that emulate videotex terminals on a micro-computer.

Allocating Videotex Databases

Before analytical approaches for designing videotex networks(VN) can be developed, it is helpful to classify these systems into groups possessing similar functional characteristics. In this research, the functional classification proposed by Cheung and Sablatash (1989) is utilized. Based on the inter-relationships between the different components of a videotex system, and the file management strategy, the authors (Cheung & Sablatash, 1989) classify VN into six major categories:

TYPE 1:Found primarily in small, independent VS, these consist of a single information retrieval system (IRS), maintaining the files provided by all information providers (IP). Type 1 VS possess a single information update system (IUS). All files are stored in a centralized videotex database.

TYPE 2:Type 2 VS contain multiple subsystems, each consisting of an IRS, an IUS and a gateway service provider (GSP). Information providers and users are affiliated with a specific subsystem. Thus, each provider interacts with the IUS of the subsystem it is affiliated to. No master database is maintained, and each subsystem's IRS is capable of retrieving only the files provided by information providers affiliated to that subsystem.

Type 2 videotex systems can be further subdivided into two categories. In the first category (Type 2.1), users and information providers (and consequently the files provided by them) can be reallocated from one subsystem to another. For the second category (Type 2.2), users and IP cannot change their affiliation from one subsystem to another.

TYPE 3:These consist of many information retrieval systems, each with a copy of the master database, and served by a single IUS. All information providers are connected to this IUS, which in turn transfers the updated videotex files to each IRS location.

TYPE 4:Like the Type 3 systems, Type 4 VS contain multiple IRSs served by a single IUS. However, unlike the Type 3 systems, a copy of the master database is not stored at each IRS. These videotex systems have a limited amount of file redundancy, since only one IRS in the VS maintains the master database. All other information retrieval systems store a subset of the overall database. At any individual IRS, if a videotex file is not available, the user request is switched to the site containing the master database. Thus, based on projected user access patterns, significant economic benefits can be realized by allocating videotex files judiciously to the information retrieval systems in the network.

TYPE 5:Type 5 systems contain multiple information retrieval and update systems. A copy of the master database is stored at each IRS. An information provider is connected to a single IUS, which in turn updates the relevant file at each IRS.

TYPE 6: In these systems, a single site on the network consisting of just an IRS stores the master database. All other sites contain an IRS and an IUS. The local information retrieval systems maintain the files provided by the IPs affiliated to that site. Each local IUS serves the information providers affiliated to that site, and updates the local database. The updated files are then transferred to the master database.

Design Issues in Configuring Videotex Networks

A videotex network consists of geographically dispersed Information Service Systems (ISS) interconnected by a telecommunications network. As discussed earlier, each ISS, in general, consists of an information retrieval system, an information update system, and a gateway service provider. Given the topology of the VN, the designer must determine:

- The information service system to which an individual user will be connected,
- The allocation of videotex files to each IRS, and
- The IUS to which each information provider will be affiliated.

In this research, we focus exclusively on the allocation of videotex files to each IRS.

A 0/1 Integer Programming Model

Allocation of videotex files to individual information retrieval systems is of relevance only in systems where a master database is not stored at each IRS. Based on the framework of VS presented earlier, it is evident that videotex file allocation is applicable to Type 4 and Type 6 systems only. The primary difference between these two types of systems result from the manner in which the file updating process is performed. In Type 4 systems, the master database is updated first and the updated files are then transferred to the IRSs that store a copy. In Type 6 systems, the local IRS is updated, and then the updated files are transferred to the site with the master copy.

File allocation in the distributed database context has been extensively researched over the past decade (Casey, 1972; Chen & Akoka, 1980; Chu, 1969; Chu, 1973; Gavish, 1985; Gavish & pirkul, 1986; Laning & Leonard, 1983; Levin & Morgan, 1976). In general, these formulations can be applied to videotex networks as well. However, due to the nature of the updating process, and the fact that queries on a specific file are either satisfied locally or communicated to the master database site, the problem formulation simplifies significantly. It must be noted that for a query there can be at most one long distance transmission, namely to the master database site.

In a videotex scenario, the location of each information provider is known. Since only a specific IP can update a particular file, given its location, the cost of update communication for each file at each IRS location can be determined a priori. In this research, the update communication cost is factored in to the fixed cost of file storage at a particular node. The objective of the mathematical formulation developed in this section is to determine which files should be stored at a specific IRS.

Let:

V^f_j = Total demand on file f (Megabytes) at IRS site j

c_j =Unit communication cost between IRS site j and location of master database ($/Megabyte)

t^f_j $=V^f_j * c_j$

=Total communication cost for file f between IRS site j and master database ($)

C^f_j =Storage and updating cost for file f at site j ($)

S^f = Size of file f (Megabyte)

Cap_j = Secondary storage capacity at IRS site j

F = Total number of videotex files

N = Total number of IRS sites

Decision Variable

X^f_j =1, if file f is stored at IRS site j
= 0, otherwise

y^f_j =1, if file f is accessed at the master database site from IRS site j
= 0, otherwise

PROBLEM P:

$$\text{Minimize:} \quad \sum_j \sum_f C^f_j * X^f_j + \sum_j \sum_f t^f_j * y^f_j \qquad (1)$$

$$\text{Subject to:} \quad \sum_f S^f * X^f_j \leq Cap_j \quad \forall j \qquad (2)$$

$$\sum_j X^f_j \geq 1 \quad \forall f \qquad (3)$$

$$X^f_j + y^f_j = 1 \qquad \forall\, f, j \qquad (4)$$

$$X^f_j,\ y^f_j \in \{0,1\} \qquad \forall\, f, j \qquad (5)$$

Using (4), and substituting for y^f_j in (1), we obtain:

Minimize:

$$T + \sum_j \sum_f (C^f_j - t^f_j) * X^f_j \qquad \text{where, } T = \sum_j \sum_f t^f_j \qquad (6)$$

Subject to: (2), (3), (5)

Thus, problem **P** can be stated as:

Maximize:

$$\sum_j \sum_f C'^f_j * X^f_j - T \qquad \text{where, } C'^f_j = t^f_j - C^f_j \qquad (7)$$

Subject to:

$$\sum_f S^f * X^f_j \leq Cap_j \qquad \forall\, j \qquad (8)$$

$$-\sum_j X^f_j \leq -1 \qquad \forall\, f \qquad (9)$$

$$X^f_j \in \{0,1\} \qquad \forall\, f, j \qquad (10)$$

The first and second terms in the objective function (1) represent respectively, the fixed cost of file storage, and the communications cost to the master database, when a file is not available locally. Constraint set (2) guarantees that secondary storage capacity is not exceeded at any IRS site. Constraint (3) ensures that a copy of the videotex database is stored in at least one IRS site.

Solving the Videotex File Allocation Problem

While problem **P** can be solved by a branch-and-bound method that uses LP relaxation, we think that the constraint set of **P** has an interesting structure that can be exploited by using Lagrangian Relaxation. A Lagrangian relaxation of a problem is obtained by identifying a set of 'complicating' constraints, whose removal results in a problem that is significantly easier to solve. These constraints are removed from the constraint set and 'thrown' into the objective function using dual multipliers. Lagrangian relaxation has been used extensively for solving various integer programming problems. A detailed exposition of this technique can be found in (Fisher, 1985). The details of our efficient solution procedure are described in the Appendix. A high level flow chart of the proposed solution procedure is presented in Figure 2.

In this section, we present the results obtained from the proposed procedure.

Computational Experiments

The Lagrangian Relaxation based solution procedure proposed in this research was programmed in FORTRAN [VIDALLOC]. All computational experiments with VIDALLOC were conducted on an IBM 3084 computer. To ascertain the quality of the results obtained from the proposed solution procedure, identical test cases were also solved using MPSX, a commercial, LP relaxation based mathematical programming software.

Generation of Test Data

VIDALLOC was tested for different combinations of the number of IRS sites (**N**=10,15,20,25,30) and total number of files to be allocated (**F**=10,20,30,40). Input data used in these experiments were generated randomly from distributions that are representative of real life values. Volume of query traffic (megabytes) on each videotex file from each site was obtained from an uniform distribution [10000-90000]. File sizes [megabytes] and storage capacity [megabytes] at each IRS were selected from uniform distributions [4000-1000] and [20000-80000] respectively. Unit query transmission cost [$/megabyte] between each IRS and the master database site, and unit file storage cost [$/megabyte] at each IRS were chosen from uniform distributions [0.02-0.06] and [0.10-0.15] respectively. For each N-F combination, five test cases (Case #1, ..., Case #5) were generated. These cases differed from each other in the ratio of update to query costs. The ratios were fixed at 10%, 20%, 30%, 40% and 50% for the five cases.

Results

The solution procedure proposed in this research is a heuristic technique, and thus optimality is not guaranteed. Consequently, it is important that the designer have an understanding of how close (or far) the solution is from the optimal solution. The quality of the solution is measured by GAP, a parameter that denotes the percentage difference between the best feasible solution and the lower bound generated by the Lagrangian procedure. One would want a

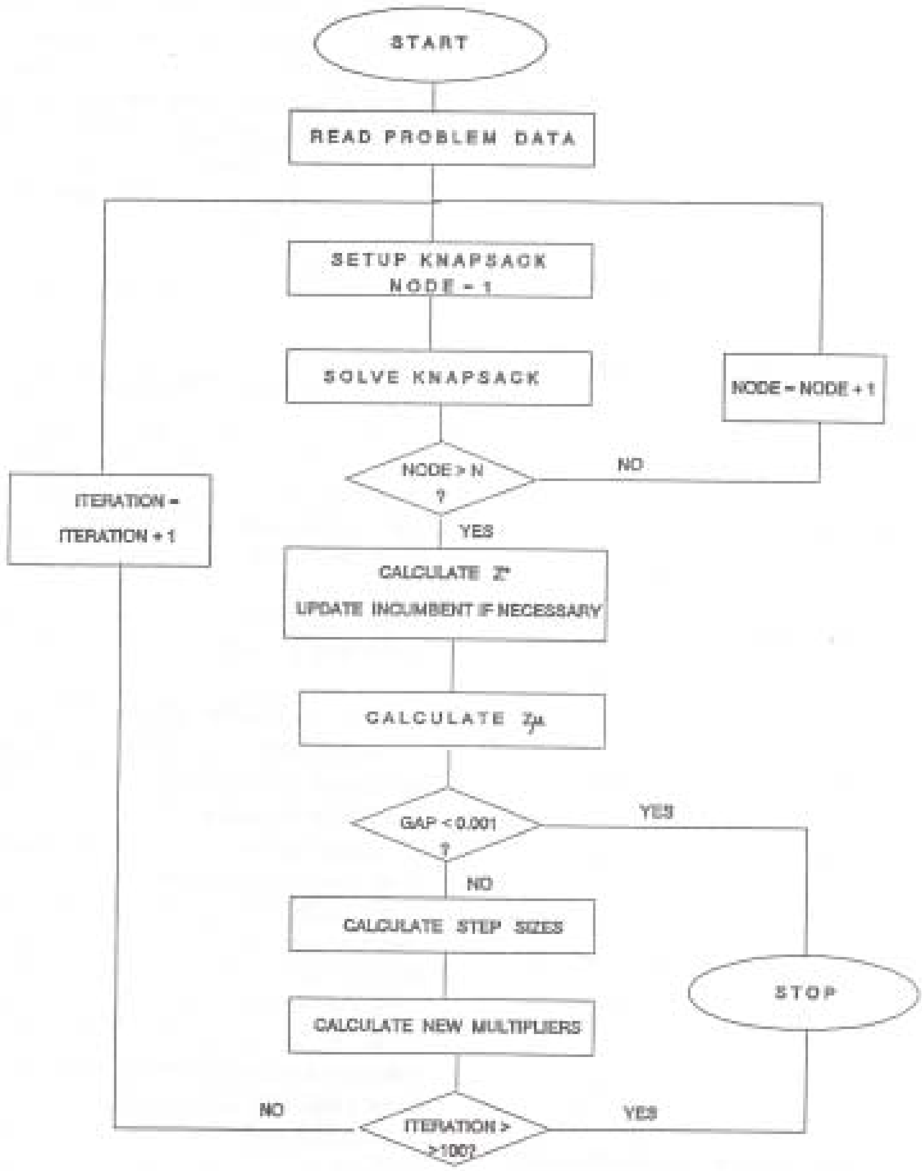

Figure 2: Flow Chart of Solution Procedure

solution procedure that (i) provides solutions where the value of GAP is close (or equal) to zero, and (ii) solves the problem swiftly.

Accordingly, we highlight two points through our computational experiments. First, we show that the proposed solution procedure provides near optimal (and often optimal) solutions. Second, we show that our procedure solves the problem quickly, at least compared to a widely used, general purpose commercial mathematical programming software package.

Table 1 presents data on the performance of the proposed solution procedure. We report the CPU time (in seconds) for solving the videotex file allocation problem using VIDALLOC, for different combinations of files (F) and IRS sites (N). We have not reported the value of GAP in Table 1 since in all but two cases, the value of GAP was zero, implying that an optimal solution had been found. In the worst case, GAP was 0.13%. It should be evident that VIDALLOC is capable of obtaining at least near optimal solutions quickly. Note, though the optimal solution was obtained in almost every instance, the proposed Lagrangian relaxation based procedure does not guarantee optimality.

		CPU TIME (seconds)					
		CASE	CASE	CASE	CASE	CASE	
N	F	#1	#2	#3	#4	#5	AVERAGE
10	10	0.03	0.031	0.031	0.031	0.032	0.031
10	20	0.061	0.059	0.062	0.06	0.062	0.061
10	30	0.096	0.097	0.098	0.094	0.095	0.096
10	40	0.126	0.125	0.123	0.122	0.127	0.125
15	10	0.044	0.043	0.044	0.042	0.041	0.043
15	20	0.08	0.081	0.082	0.082	0.082	0.081
15	30	0.118	0.118	0.12	0.12	0.121	0.119
15	40	0.152	0.15	0.15	0.151	0.149	0.150
20	10	0.058	0.056	0.057	0.057	0.057	0.057
20	20	0.114	0.116	0.115	0.117	0.117	0.116
20	30	0.18	0.18	0.179	0.175	0.176	0.178
20	40	0.266	0.264	0.258	0.252	0.263	0.261
25	10	0.068	0.068	0.067	0.065	0.068	0.067
25	20	0.139	0.141	0.142	0.141	0.142	0.141
25	30	0.211	0.211	0.21	0.212	0.205	0.210
25	40	0.327	0.32	0.319	0.322	0.319	0.321
30	10	0.077	0.078	0.078	0.079	0.079	0.078
30	20	0.158	0.16	0.165	0.164	0.164	0.162
30	30	0.245	0.247	0.247	0.243	0.243	0.245
30	40	0.35	0.343	0.346	0.338	0.339	0.343

Table 1: CPU Time for Executing Vidalloc

Table 2 presents the execution time (in seconds) for solving the videotex file allocation problem using VIDALLOC and MPSX. For the largest problem (N=25, F=30), MPSX could not find an optimal solution in 60 seconds of CPU time. In all other cases, the value of the objective function was identical for MPSX and VIDALLOC. It must be noted, however, that the MPSX problems were executed on an IBM 3090/600E computer utilizing the vector facility. Due to unavoidable constraints, VIDALLOC was executed on an IBM 3084. We believe that VIDALLOC's execution time could be even lower had we conducted all the numerical experiments on the faster 3090/600E computer. Inspite of the difference in computing power of the two machines, it should be apparent from Table 2 that, on the average, VIDALLOC solves the same problem approximately forty times faster than MPSX.

Conclusion

In this paper, we briefly outline commercial implementations of videotex systems in different countries and discuss some of the potential organizational uses of videotex technology. We strongly believe that, in the United States, this technology will have a major impact in the recent future, predominantly due to the proposed 'roll out' of ISDN by the mid 1990s. In addition, we formulate a 0/1 integer programming formulation of the videotex file allocation problem, and propose a Lagrangian relaxation based solution procedure. Extensive computational experiments with the proposed technique prove its efficiency in obtaining near optimal solutions quickly.

As far as designing a videotex network is concerned, a major design issue, namely the assignment of users (subscribers) to individual IRS sites, has been ignored in this research. Success of a videotex network relies heavily on how inexpensively users can access such a system. Thus, this user assignment problem reduces to locating concentrators in different cities that can be accessed via local telephone calls. Future research on videotex network design should address this issue.

The proposed solution procedure provides near optimal solutions quickly. This is primarily due to the fact that the upper bound obtained from the Lagrangian relaxation process out-performs its LP counterpart. However, to guarantee optimality, future research should incorporate the technique

N	F	INT. VAR.	MPSX	VIDALLOC
			(sec.)	(sec.)
10	10	100	1.92	0.029
10	15	150	2.40	0.040
10	20	200	3.36	0.054
10	25	250	3.42	0.064
10	30	300	3.46	0.091
15	10	150	2.40	0.043
15	15	225	2.90	0.058
15	20	300	3.84	0.089
15	25	375	3.87	0.093
15	30	450	4.32	0.120
20	10	200	3.36	0.054
20	15	300	2.88	0.078
20	20	400	4.46	0.116
20	25	500	4.22	0.119
20	30	600	6.53	0.175
25	10	250	3.84	0.065
25	15	375	4.38	0.092
25	20	500	4.08	0.128
25	25	625	5.53	0.145
25	30	750	60.00	0.322
		AVERAGE	3.746	0.087

Table 2: Comparison of Execution Times for MPSX and Vidalloc

proposed in this research within an overall branch-and-bound algorithm.

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Appendix

For problem **P**, a relaxation can be obtained by dualizing the constraints in (9). Let μ_f represent the Lagrange multiplier associated with each constraint in (9). The relaxation obtained is:

$$(P_\mu) \quad \text{Maximize: } Z_\mu$$

$$= \sum_f \sum_j \hat{C}^f_j * X^f_j + \sum_f \mu_f [\sum_j X^f_j - 1] \qquad (11)$$

$$\text{Subject to:} \quad \sum_f S^f * X^f_j \leq Cap_j \quad \forall j \qquad (12)$$

$$X^f_j \in \{0,1\} \quad \forall f, j \qquad (13)$$

The structure of $\mathbf{P}_\mu$ allows it to be decomposed into j independent 0/1 Knapsack problems of the form:

$$\text{Maximize: } \sum_f (C'^f_j + \mu_f) * X^f_j \quad (14)$$

$$\text{Subject to: } \sum_f S^f * X^f_j \leq Cap_j \quad (15)$$

$$X^f_j \in \{0,1\} \quad \forall f \quad (16)$$

We utilize the efficient solution procedure proposed by Nauss (1976) for solving a 0/1 knapsack problem. It is well known that Z_μ provides the upper bound on the optimal solution to **P**. To obtain the tightest upper bound involves solving the Lagrangian dual:

$$\text{(D)} \quad \min_{\mu \geq 0} Z_\mu \quad (17)$$

We solve (**D**) approximately using the sub-gradient optimization method. This method starts at an initial point μ^0 and generates a sequence of μ^k as:

$$\mu^{k+1} = \mu^k + t^k.S^k \quad (18)$$

where, t^k is a positive scalar step size, and S^k is the sub-gradient or direction vector. For our problem, S^k consists of the difference between the left-hand-side and the right-hand-side of the constraints in (9), associated with the current Lagrangian solution. It has shown (Fisher, 1985) that the following formula is effective for obtaining the value of the step size t^k:

$$t^k = \frac{\lambda^k (Z_\mu - Z^*)}{\| S^k \|^2}, \quad (19)$$

where, λ^k is a scalar satisfying $0 - \lambda^k - 2$, and Z^* is the objective function value of the best known feasible solution to **P**. Each time a new set of multipliers is obtained, $\mathbf{P}_\mu$ is solved. In the course of searching for a set of better multipliers, a sequence of λ^k is determined by setting $\lambda^0 = 2$ and halving λ^k whenever Z_μ fails to increase in some fixed number of iterations. Also, at various points in the sub-gradient procedure one may obtain a solution to P_μ that is feasible to P. If so, it is compared to the incumbent. If it is found to be better than the incumbent solution, then the incumbent solution (Z^*) is updated. The optimal objective function value to **P** lies between Z_μ and Z^* is calculated as:

$$GAP = \frac{Z_\mu - Z^*}{Z_\mu} \times 100 \quad (20)$$

GAP is used as a measure of the quality of the incumbent feasible solution to **P**. The heuristic is halted when the value of GAP is less than or equal to 0.10 %.

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